FLOW OF HEAT THROUGH PIPE COVERING

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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FLOW OF HEAT THROUGH PIPE COVERING

A THESIS

PRESENTED BY

FRANK H. SCHWARTZ AND ARTHUR W. ZEMKE

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

MAY 27, 1920

APPROVED:

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Dean of Engineering Studies

Dean of Cultural Studies

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FOREWORD.

With the every day rise of cost in fuel, labor, material, and transportation, the modern tendency is to reduce all losses in the power plant to a minimum. A loss of quite significance which up to a few years ago was considered a small item, is due to uncovered steam pipes. Prior to year 1916, several men attempted to perform tests on coverings, but their results were either incomplete or unreliable. In 1916 L. B. McMillan carried on an extensive investigation at the University of Wisconsin, and was the first one to obtain trustworthy results, which proved that a saving from 75 per cent to 90 per cent of the heat loss through radiation and convection from bare pipe, could be saved by a covering.

In preparing this thesis, the aim of which is to carry on the work, started by L. B. McMillan, we wish to record our appreciation of the assistance and suggestions that have

been received from time to time from James Clinton Peebles, Associate Professor of Experimental Engineering, Armour Institute of Technology.

We are also indebted to L. B. McMillan for information obtained from his treatise on "The Heat Insulating Properties of Commercial Pipe Covering.", A.S.M.E. Trans. Vol. 37, 1916.

F.H.S.
A.W.Z.

Chapter I.

INTRODUCTION.

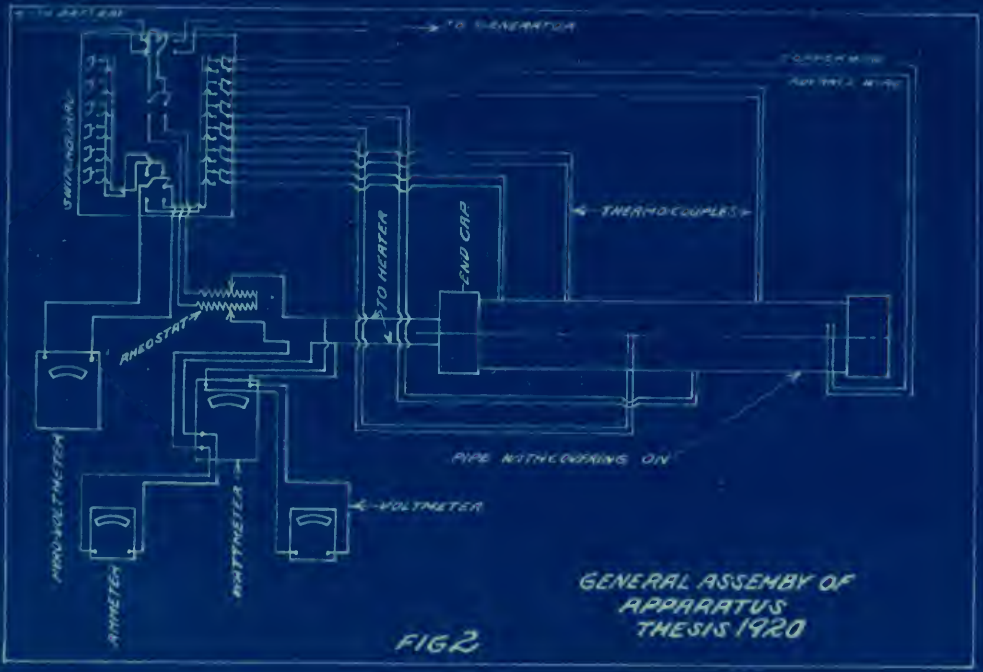
To insulate effectively heated surfaces, primarily steam pipes, against loss of heat, the question arises as to what material shall be used, and what thickness of material shall be used for greatest economy. It is the aim of this thesis to determine the amount of heat loss per unit of surface per hour per degree temperature difference, for some of the coverings most commonly used. To make the results of value, the investigations were carried on under conditions as near those of power plant practice, as possible.

The effect on heat losses of varying the temperature difference between pipe surface and air, between limits of 60 and 400 degrees fahr., has been thoroughly investigated. Also different thicknesses from I to 3 in. were tested. In addition to the above, the mathematical treatment of the subject by L. B. McMillan was

applied to these tests, and the results compared.

Chapter 2.

DESCRIPTION OF APPARATUS.


← TO BATTERY
→ TO GENERATOR
COPPER WIRE
SWITCHBOARD
TO HEATER
END CAP
← THERMO-COUPLES →
RHEOSTAT
PIPE WITH COVERING ON
MILLI-VOLTMETER
AMMETER
WATTMETER
← VOLTMETER

GENERAL ASSEMBY OF
APPARATUS
THESIS 1920

FIG 2

The general arrangement of the apparatus is shown in Fig. 2. The test pipe is a 6 I/4 ft. section of standard 5-in. steel pipe with an outside diameter of 5.56-in. It contains an electric heater, (illustrated in Fig. I) consisting of a 4-in. boiler tube with a layer of ordinary iron wire wound non-inductively, and a single thickness of asbestos tape between, as insulating material. The ends of the wire are coupled through a switch to a source of electric energy: either a generator or battery. The tube is also provided with a steel shoulder at each end (outside diameter 4 I5/I6-in.) the purpose of which is to make the heater lie snugly in the pipe, and at the same time to seal the ends, thus preventing direct loss of heat.

To reduce to a minimum loss of heat from the ends of pipe by radiation from the metal surface, the pipe is provided with caps,

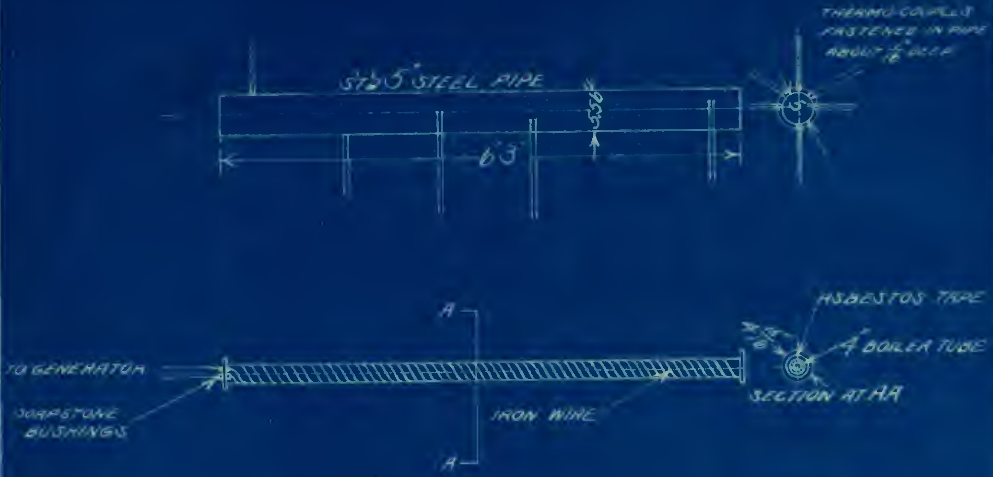

STD 5" STEEL PIPE
.556
63"
THERMO-COUPLES
FASTENED IN PIPE
ABOUT 1/16" DEEP
A
A
TO GENERATOR
SOAPSTONE
BUSHINGS
IRON WIRE
ASBESTOS TAPE
1/16"
4" BOILER TUBE
SECTION AT AA

FIG 1

DETAILS OF
PIPE AND HEATER
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(designated in the illustration as end caps) about 4-in. in thickness. They are made of good heat insulating material, such as asbestos cement.

The temperature difference, that is, the difference in temperature between pipe and room, is measured by six thermo-couples placed at equal distances apart, on the top, side, and bottom. These couples are made of copper and advance wire, the latter being manufactured by Driver-Harris Wire Co. Each couple was imbedded in the metal of the pipe. A hole about I/I6-in. deep and just large enough to admit the point forming the junction of the two metals of the couple, was drilled into the pipe, and after insertion the steel was forced down against this point by means of a blunt center punch. This metal to metal contact secured in this way reduced to a minimum the chances for a drop in temperature from the me-

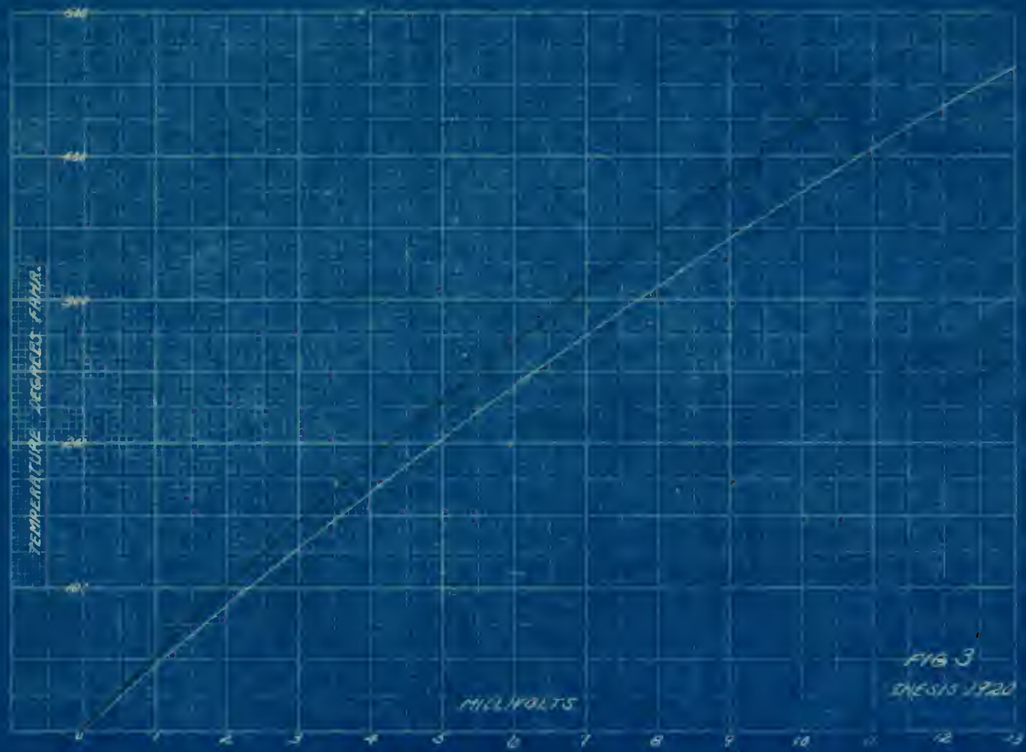

FIG 3

THESIS 1920

tal of the pipe to the couple. The couple leads are well insulated: the copper with a single covering of silk; the advance with rubber tubing.

A pyro-volter is used to measure the e. m. f. of the couples and indicates it in millivolts. This instrument was calibrated and a relation established between the millivolts indicated, and temperature, (deg. Fahr.) the result of which appeares in the form of a curve, Fig. 3.

Direct current at II0 volts was used to supply the energy for the tests. During the day it was furnished by a 200 KW. Western Electric generator driven by a Ball-Wood steam engine, located in the power plant of Armour Institute of Technology. During the night it was furnished by a battery located in the Electric Laboratory of Armour Institute of Technology. The current is regulated by means of a potential rheostat.

The instrument for measuring the energy supplied to the pipe, is a wattmeter. As a check and to safeguard against any shorted circuits, a Weston D. C. voltmeter and a Weston D. C. ammeter are connected as illustrated in Fig. 2. All of these instruments were calibrated in the Electric Laboratory of the Armour Institute of Technology.

Chapter 3.

METHOD OF PERFORMING TEST.

Before the coverings were tested, each section was weighed, and its thickness at each end was measured. The thickness so measured is called the actual thickness in the tables. The sections were then placed on the test pipe, and fitted carefully so that all joints were snug, all cracks cemented with asbestos cement, and canvass pasted over seams, as in actual power plant practice. After this the covering was subjected to medium heat for at least two days and allowed to dry.

When the covering was ready for testing, the current was lowered to such a value as to make the power input about 200 watts, and maintained at exactly this value for at least five hours to allow conditions to become constant. Readings were then taken every hour- for at least four hours-of room temperature, temperature of the cold end of the thermocouples, (in this test at the back of the

switchboard) e. m. f. of the thermo-couples, temperature under canvass, and amount of energy supplied. The supply of energy was then increased about I50 watts and test repeated. This was continued until a temperature difference of about 400 degrees Fahrenheit was reached. Each covering was tested in the same manner.

Chapter 4.

LABORATORY DATA AND RESULTS.

Table I

Sponge Felt Covering No. I

Size of pipe, inches....................5

Thickness of covering, nominal, in....2

Thickness of covering, actual, in.....2

Weight per foot of length, lbs.....9.2I

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
I2/6/I9	9.00AM	360	8.74	80
"	I0.00 "	"	8.80	8I
I2/9/I9	8.30 "	350	8.90	80
"	2.00PM	"	9.48	80
"	3.00 "	"	9.43	82
"	5.00 "	"	9.33	80
I2/II/I9	I.00 "	300	7.I8	82
"	2.00 "	"	7.33	82
"	3.00 "	"	7.34	82
"	4.00 "	"	7.38	82
"	5.00 "	"	7.45	8I
"	6.00 "	"	7.4I	83
"	7.00 "	"	7.43	84

Table I (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
I2/II/I9	9.00PM	300	7.49	80
I2/I2/I9	II.00AM	250	6.40	85
"	2.00PM	"	6.4I	84
"	3.00 "	"	6.42	84
"	4.00 "	"	6.43	83
"	5.00 "	"	6.43	82
I2/I3/I9	8.00AM	350	8.70	74
"	I0.30 "	"	8.70	78
"	II.I5 "	"	8.7I	78
"	I2.00	"	8.73	78
I2/I6/I9	9.00AM	400	I0.20	78
"	I0.00 "	"	I0.20	78
"	I0.30 "	"	I0.20	78
"	II.00 "	"	I0.20	79
"	I2.00	"	I0.00	80
"	I.00PM	"	I0.00	80
I2/I7/I9	8.30AM	450	II.80	78

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Table I (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
12/17/19	9.30AM	450	11.70	78
"	10.30 "	"	11.70	78
"	11.30 "	"	11.70	78
12/18/19	10.30 "	100	2.57	82
"	12.00	"	2.56	82
"	1.00PM	"	2.58	82
"	2.00 "	"	2.57	82
"	3.00 "	"	2.57	83

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Table I (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
I2/6/I9	9.00AM	80	II4	II4
"	I0.00 "	80	II6	II5
I2/9/I9	8.30 "	80	II6	II6
"	2.00PM	80	II5	II6
"	3.00 "	80	II8	II9
"	5.00 "	80	II6	II7
I2/II/I9	I.00 "	82	II2	III
"	2.00 "	82	III	II2
"	3.00 "	82	III	III
"	4.00 "	82	III	III
"	5.00 "	8I	II2	III
"	6.00 "	83	II3	II3
"	7.00 "	84	II4	II5
"	9.00 "	80	III	II2
I2/I2/I9	II.00AM	85	III	II2
"	2.00PM	84	III	II2
"	3.00 "	84	II0	II0

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Table I (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
I2/I2/I9	4.00PM	83	II0	II0
"	5.00 "	82	I08	I09
I2/I3/I9	8.00AM	74	I08	I09
"	II.30 "	78	II2	II2
"	I2.00	78	II3	II3
I2/I6/I9	9.00AM	78	II8	II7
"	I0.00 "	78	II8	II7
"	I0.30 "	78	II8	II7
"	II.00 "	79	II9	II8
"	I2.00	80	I20	II9
"	I.00PM	80	I20	II9
I2/I7/I9	8.30AM	78	I24	I23
"	9.30 "	78	I24	I23
"	I0.30 "	78	I24	I22
"	II.30 "	78	I24	I22
I2/I8/I9	I0.30 "	82	94	94
"	I2.00	82	95	95

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Table I (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
12/18/19	1.00PM	82	95	95
"	2.00 "	82	94	95
"	3.00 "	83	95	96

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Table I (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
1	100	2.57	83	83	191	95	108
2	250	6.43	82	82	337	108.5	255
3	300	7.49	80	80	371	111.5	291
4	350	8.73	78	78	411	112.5	333
5	400	10.00	80	80	452	119.5	372

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Table I (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
I	I00	0.329	2.I8	I.85I	85.0	340
2	250	0.348	3.00	2.652	88.4	850
3	300	0.367	3.2I	2.843	88.5	I020
4	350	0.374	3.48	3.I06	89.4	I200
5	400	0.382	3.79	3.408	89.9	I360

Table 2

Sponge Felt Covering No. 2

Size of pipe, inches....................5

Thickness of covering, nominal, in....I

Thickness of covering, actual, in..0.8I

Weight per foot of length, lbs.....2.98

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
I/2I/20	9.00AM	I00	I.50	82
"	I0.00 "	"	I.5I	82
"	II.00 "	"	I.52	82
"	I2.00	"	I.52	82
"	I.00PM	"	I.50	82
"	3.00 "	"	I.52	82
"	4.00 "	"	I.54	82
"	5.00 "	"	I.52	82
I/22/20	I.00 "	200	3.I0	80
"	2.00 "	"	3.00	80
I/23/20	2.00 "	"	2.97	82
"	4.00 "	"	2.93	85
I/27/20	8.30AM	300	4.80	84

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Table 2 (continued)

Date	Time	Watts	Millivolts	Temp. Cold end Deg. Fahr.
I/27/20	I.00PM	300	4.65	86
I/28/20	9.00AM	"	4.27	82
"	I0.00 "	"	4.35	82
"	II.00 "	"	4.37	82
"	I2.00	"	4.30	85
"	I.00PM	"	4.3I	82
"	2.00 "	"	4.35	82
"	3.00 "	"	4.30	83
"	4.00 "	"	4.30	83
I/29/20	2.00 "	400	5.27	85
"	3.00 "	"	5.37	86
"	4.00 "	"	5.40	86
"	5.00 "	"	5.50	87
I/30/20	II.00AM	"	6.I0	84
"	2.00PM	"	6.03	86
"	3.00 "	"	5.93	85
"	4.00 "	"	5.93	85
"	5.00 "	"	5.90	85

Table 2 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
I/30/20	6.00PM	300	5.90	84
2/2/20	I.00 "	"	7.22	87
"	2.00 "	"	7.20	85
"	3.00 "	"	7.20	85
"	4.00 "	"	7.20	85
"	5.00 "	"	7.20	85
2/4/20	I.00 "	600	8.53	82
"	2.00 "	"	8;60	8I
"	3.00 "	"	8.60	8I
"	4.00 "	"	8.60	8I
"	5.00 "	"	8.64	82
2/5/20	2.00 "	650	9.00	83
"	3.00 "	"	9.00	83
"	4.00 "	"	9.20	82
"	5.00 "	"	9.00	84

Table 2 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
I/2I/20	9.00AM	82	98	98
"	I0.00 "	82	I00	I00
"	II.00 "	82	I00	I00
"	I2.00	82	I00	I00
"	I.00PM	82	99	99
"	3.00 "	82	99	99
"	4.00 "	82	I00	I00
"	5.00 "	82	I00	I00
I/22/20	I.00 "	80	III	II2
"	2.00 "	80	III	II2
I/23/20	2.00 "	82	II2	II2
"	4.00 "	85	II4	II4
I/27/20	8.30AM	84	I28	I28
"	I.00PM	86	I29	I30
I/28/20	9.00AM	82	I25	I25
"	I0.00 "	82	I25	I25
"	II.00 "	82	I26	I26
"	I2.00	85	I27	I27

Table 2 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
I/28/20	I.00PM	82	I26	I26
"	2.00 "	82	I25	I26
"	3.00 "	83	I26	I26
"	4.00 "	83	I26	I26
I/29/20	2.00 "	85	I35	I36
"	3.00 "	86	I36	I38
"	4.00 "	86	I38	I40
"	5.00 "	87	I40	I4I
I/30/20	II.00AM	84	I39	I40
"	2.00PM	86	I40	I4I
"	3.00 "	85	I39	I40
"	4.00 "	85	I40	I40
"	5.00 "	85	I40	I40
"	6.00 "	84	I39	I40
2/2/20	I.00 "	88	I56	I58
"	2.00 "	86	I53	I55
"	3.00 "	85	I53	I55
2/2/20	4.00 "	86	I53	I54

Table 2 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
2/2/20	5.00PM	86	I54	I56
2/4/20	I.00 "	82	I62	I64
"	2.00 "	8I	I60	I62
"	3.00 "	82	I6I	I62
"	4.00 "	8I	I6I	I62
"	5.00 "	84	I62	I64
2/5/20	2.00 "	84	I72	I73
"	3.00 "	83	I70	I7I
"	4.00 "	82	I69	I7I
"	5.00 "	85	I70	I73

Table 2 (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	I00	I.52	82	82	I47	I00	65
2	200	2.93	85	85	208	II4	I23
3	300	4.30	83	83	259	I26	I76
4	400	5.90	84	84	3I9	I39.5	235
5	500	7.20	85	86	366	I55	28I
6	650	9.00	84	85	425	I7I.5	34I

Table 2 (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
I	I00	0.547	2.00	I.453	72.6	340
2	200	0.578	2.28	I.702	74.6	680
3	300	0.607	2.53	I.923	76.0	I020
4	400	0.605	2.87	2.265	79.I	I360
5	500	0.632	3.I5	2.5I8	80.0	I700
6	650	0.678	4.56	3.882	85.0	22I0

Table 3

Sponge Felt Covering No. 3

Size of pipe, inches....................5
Thickness of covering, nominal, in....3
Thickness of covering, actual, in..3.I3
Weight per foot of length, lbs....20.I0

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
I/7/20	I2.00	300	I0.I0	87
"	I.00PM	"	I0.I0	86
"	2.00 "	"	I0.30	86
"	3.00 "	"	I0.30	86
"	4.00 "	"	I0.30	86
"	5.00 "	"	I0.30	84
I/8/20	I.00 "	350	II.70	84
"	2.00 "	"	II.80	84
"	3.00 "	"	II.80	85
"	4.00 "	"	II.80	85
"	5.00 "	"	II.80	85
I/9/20	I.00 "	400	I3.20	82
"	2.00 "	"	I3.20	82

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Table 3 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
I/9/20	3.00PM	400	I3.30	82
"	4.00 "	"	I3.30	82
"	5.00 "	"	I3.30	82
I/I0/20	9.00AM	450	I4.I0	78
"	I0.00 "	"	I4.30	79
"	II.00 "	"	I4.30	80
"	I2.00	"	I4.30	80
"	I.00PM	"	I4.30	76
"	2.00 "	"	I4.30	76
"	3.00 "	"	I4.30	76
I/I3/20	I.00 "	200	6.25	85
"	2.00 "	"	6.3I	85
"	3.00 "	"	6.30	85
"	4.00 "	"	6.30	85
"	5.00 "	"	6.30	84
I/I4/20	I.00 "	I00	3.40	80
"	2.00 "	"	3.38	80

Table 3 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
I/I4/20	3.00PM	I00	3.30	80
"	4.00 "	"	3.30	80
"	5.00 "	"	3.30	80

Table 3 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
I/7/20	I2.00	87	II5	II9
"	I.00PM	86	II5	II9
"	2.00 "	85	II5	II9
"	3.00 "	86	II4	II8
"	4.00 "	86	II4	II8
"	5.00 "	84	II3	II8
I/8/20	I.00 "	84	II4	II8
"	2.00 "	84	II5	II9
"	3.00 "	85	II7	I2I
"	4.00 "	85	II8	I2I
"	5.00 "	85	II7	I20
I/9/20	I.00 "	82	I20	I22
"	2.00 "	82	I20	I22
"	3.00 "	82	I20	I22
"	4.00 "	82	I20	I2I
"	5.00 "	82	I20	I2I
I/I0/20	9.00AM	78	II8	I22
"	I0.00 "	79	II8	I20

Table 3 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
1/10/20	11.00AM	80	119	122
"	12.00	80	119	123
"	1.00PM	76	116	119
"	2.00 "	76	116	119
"	3.00 "	76	116	119
1/13/20	1.00 "	85	105	106
"	2.00 "	85	104	106
"	3.00 "	85	104	106
"	4.00 "	85	104	105
"	5.00 "	84	104	105
1/14/20	1.00 "	80	92	93
"	2.00 "	80	93	94
"	3.00 "	80	93	94
"	4.00 "	80	93	94
"	5.00 "	80	93	94

Table 3 (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End. Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	I00	3.30	80	80	2I8	93.5	I38
2	300	I0.30	84	84	465	II5.5	38I
3	350	II.80	85	85	5I2	II8.5	427
4	400	I3.30	82	82	554	I20.5	472
5	450	I4.30	76	76	578	II7.5	502

Table 3 (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
1	100	0.258	2.35	2.092	97.6	340
2	300	0.280	3.825	3.645	95.3	1020
3	350	0.292	4.24	3.948	93.1	1190
4	400	0.302	4.80	4.498	93.7	1365
5	450	0.319	5.175	4.856	93.8	1530

Table 4

Sponge Felt Covering No. 4

Size of pipe, inches....................5

Thickness of covering, nominal, in.....I

Thickness of covering, actual, in...I.05

Weight per foot of length, lbs......4.58

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
2/I7/20	2.00PM	I00	I.7I	88
"	3.00 "	"	I.50	89
"	4.00 "	"	I.63	89
"	5.00 "	"	I.62	89
2/I9/20	I.00 "	"	I.4I	84
"	2.00 "	"	I.42	84
"	3.00 "	"	I.40	84
"	4.00 "	"	I.39	84
"	5.00 "	"	I.42	84
2/20/20	I2.00	"	I.6I	86
"	I.00PM	"	I.55	86
"	4.00 "	"	I.55	84
2/23/20	I.00 "	200	3.48	83

Table 4 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
2/23/20	2.00PM	200	3.38	82
"	3.00 "	"	3.43	82
"	4.00 "	"	3.38	84
"	5.00 "	"	3.30	84
2/24/20	12.00	450	7.35	83
"	1.00PM	"	7.40	85
"	3.00 "	"	7.30	83
"	4.00 "	"	7.30	82
"	5.00 "	"	7.30	86
2/25/20	2.00 "	550	8.82	84
"	3.00 "	"	8.91	81
"	4.00 "	"	9.00	80
"	5.00 "	"	9.05	80
2/26/20	2.00 "	300	4.88	83
"	3.00 "	"	5.10	84
"	4.00 "	"	5.13	80
"	5.00 "	"	5.12	80
4/5/20	2.00 "	60	1.155	78

Table 4 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
4/5/20	3.00PM	60	1.10	80
"	4.00 "	"	.98	78
"	5.00 "	"	.99	79
"	6.00 "	"	.99	78
"	7.00 "	"	.98	78
"	8.00 "	"	.92	77
"	9.00 "	"	.92	77
2/6/20	1.00 "	150	2.58	79
"	2.00 "	"	2.50	79
"	3.00 "	"	2.48	82
"	4.00 "	"	2.47	82
"	5.00 "	"	2.43	81
"	6.00 "	"	2.47	80
"	7.00 "	"	2.47	80
4/7/20	1.00 "	380	5.85	81
"	3.00 "	"	6.45	83
"	4.00 "	"	6.45	85
"	5.00 "	"	6.40	85

Table 4 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
4/8/20	I.00PM	470	7.75	78
"	2.00 "	"	7.79	77
"	3.00 "	"	7.80	78
"	4.00 "	"	7.85	85
"	5.00 "	"	7.86	85
4/9/20	2.00 "	700	9.97	76
"	5.00 "	"	II.50	78
"	6.30 "	"	II.IO	78
2/26/20	8.30AM	95	I.60	76
"	II.00 "	"	I.60	76
"	I2.00	"	I.60	79

Table 4 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
2/I7/20	2.00PM	88	I02	I03
"	3.00 "	89	I03	I04
"	4.00 "	89	I03	I04
"	5.00 "	88	I02	I04
2/I9/20	I.00 "	83	97	98
"	2.00 "	84	97	99
"	3.00 "	84	98	99
"	4.00 "	84	97	99
"	5.00 "	83	97	99
2/20/20	I2.00	86	99	I00
"	I.00PM	86	99	I0I
"	4.00 "	84	97	99
2/23/20	I.00 "	83	II2	I08
"	2.00 "	82	I07	II0
"	3.00 "	80	I06	II0
"	4.00 "	84	I08	II2
"	5.00 "	84	I08	II2
2/24/20	I2.00	83	I38	I38

Table 4 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
2/24/20	1.00PM	85	138	138
"	3.00 "	83	136	136
"	4.00 "	82	136	136
"	5.00 "	86	138	138
2/25/20	2.00 "	84	146	140
"	3.00 "	81	144	146
"	4.00 "	80	144	146
"	5.00 "	79	142	145
2/26/20	2.00 "	82	123	127
"	3.00 "	82	120	122
"	4.00 "	79	116	118
"	5.00 "	78	116	118
4/5/20	2.00 "	78	88	86
"	3.00 "	79	90	87
"	4.00 "	78	89	86
"	5.00 "	78	88	86
"	6.00 "	78	87	86
"	7.00 "	78	87	86

Table 4 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
4/5/20	8.00PM	77	87	85
"	9.00 "	77	87	85
4/6/20	I.00 "	79	98	96
"	2.00 "	80	99	96
"	3.00 "	8I	I0I	98
"	4.00 "	82	I0I	98
"	5.00 "	8I	I0I	98
"	6.00 "	80	I00	97
"	7.00 "	80	I00	97
4/7/20	I.00 "	8I	I00	97
"	3.00 "	83	I3I	I27
"	4.00 "	84	I3I	I28
"	5.00 "	85	I32	I28
4/8/20	I.00 "	78	I35	I3I
"	2.00 "	77	I35	I3I
"	3.00 "	78	I36	I32
"	4.00 "	85	I42	I39

Table 4 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
4/8/20	5.00PM	85	I43	I38
4/9/20	2.00 "	76	I43	I40
"	5.00 "	79	I60	I54
"	6.30 "	79	I6I	I56
2/26/20	8.30AM	77	89	90
"	II.00 "	75	90	92
"	I2.00	78	92	93

Table 4 (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	95	I.60	79	78	I46	92.5	67
2	I50	2.47	80	80	I84	98.5	I04
3	200	3.30	84	84	22I	II0.0	I37
4	380	6.40	85	85	338	I30.0	253
5	470	7.86	85	85	389	I40.5	304

Table 4 (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
I	95	0.505	2.02	I.5I5	75.0	324
2	I50	0.5I3	2.I5	I/637	76.0	5I0
3	200	0.5I9	2.30	I.78I	77.4	680
4	380	0.535	2.96	2.425	82.I	I290
5	470	0.550	3.27	2.720	83.2	I600

Table 5

Asbestos Sponge Felt Covering No. 5

Size of pipe, inches....................5

Thickness of covering, nominal, in.....I

Thickness of covering, actual, in..0.902

Weight per foot of length, lbs......4.IO

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/I/20	2.00PM	I50	3.20	8I
"	3.00 "	"	3.I5	8I
"	4.00 "	"	3.20	8I
"	5.00 "	"	3.I0	80
"	6.00 "	"	3.00	8I
3/2/20	II.00AM	300	5.85	82
"	I2.00	"	5.90	82
"	I.00PM	"	5.90	84
"	2.00 "	"	5.95	86
"	3.00 "	"	5.95	85
"	4.00 "	"	5.95	84
"	5.00 "	"	6.00	84

Table 5 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/3/20	11.00AM	450	9.15	82
"	12.00	"	9.15	84
"	1.00PM	"	9.25	85
"	2.00 "	"	9.30	84
"	3.00 "	"	9.15	87
"	4.00 "	"	9.15	87
"	5.00 "	"	9.25	86
3/4/20	11.00AM	600	11.00	88
"	12.00	"	11.75	86
"	1.00PM	"	11.80	82
"	2.00 "	"	11.90	81
"	3.00 "	"	12.00	81
"	4.00 "	"	12.15	81
"	5.00 "	"	12.15	81

Table 5 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/1/20	2.00PM	80	99	101
"	3.00 "	81	99	101
"	4.00 "	81	98	101
"	5.00 "	80	98	101
"	6.00 "	81	100	102
3/2/20	11.00AM	82	117	120
"	12.00	82	119	121
"	1.00PM	84	120	122
"	2.00 "	86	122	124
"	3.00 "	85	121	123
"	4.00 "	84	118	122
"	5.00 "	84	118	122
3/3/20	11.00AM	82	131	135
"	12.00	84	134	137
"	1.00PM	80	135	136
"	2.00 "	84	136	137
"	3.00 "	87	137	138

Table 5 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/3/20	4.00PM	87	139	140
"	5.00 "	87	138	140
3/4/20	11.00AM	89	148	151
"	12.00	86	149	150
"	1.00PM	82	147	149
"	2.00 "	82	148	150
"	3.00 "	82	147	150
"	4.00 "	82	147	150
"	5.00 "	82	148	150

Table 5 (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg: Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	I50	3.I3	8I	80	2II.I	200	I30.I
2	300	6.00	84	84	324.0	II9.5	240.0
3	450	9.25	86	86	433.0	I39	347.0
4	600	I2.I5	84	84	510.0	I48.8	436.0

Table 5 (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
I	I50	0.4I0	2.29	I.880	82.3	508
2	300	0.443	2.92	2.477	84.8	I020
3	450	0.462	3.55	3.088	86.7	I530
4	600	0.487	4.30	3.8I3	88.3	2040

Table 6

85% Magnesia Covering (IOyrs. old)

Size of pipe, inches.........................5

Thickness of covering, nominal, in.......I

Thickness of covering, actual, in.....0.98

Weight per foot of length, lbs.........2.80

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/22/20	I.00PM	I50	2.60	80
"	2.00 "	"	2.50	82
"	3.00 "	"	2.30	86
"	4.00 "	"	2.30	83
"	5.00 "	"	2.30	83
3/23/20	I.00 "	300	4.70	85
"	2.00 "	"	4.70	84
"	3.00 "	"	4.60	86
"	4.00 "	"	4.60	88
"	5.00 "	"	4.60	90
3/24/20	9.00AM	450	7.20	88
"	II.00 "	"	7.I0	88
"	I2.00	"	7.20	88

Table 6 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/24/20	1.00PM	450	7.20	86
"	2.00 "	"	7.25	87
"	3.00 "	"	7.25	86
"	4.00 "	"	7.25	89
"	5.00 "	"	7.40	90
3/25/20	8.00AM	600	10.30	87
"	12.00	"	10.30	89
"	1.00PM	"	10.50	86
"	2.00 "	"	10.50	86
"	3.00 "	"	10.70	86
"	4.00 "	"	10.10	86
"	5.00 "	"	10.10	85
"	5.30 "	"	10.10	86

Table 6 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/22/20	I.00PM	80	I02	I03
"	2.00 "	82	I02	I04
"	3.00 "	86	I04	I05
"	4.00 "	83	I03	I04
"	5.00 "	83	I03	I04
3/23/20	I.00 "	85	II9	I20
"	2.00 "	84	II8	I20
"	3.00 "	86	I22	I23
"	4.00 "	88	I22	I24
"	5.00 "	90	I22	I24
3/24/20	9.00AM	88	I37	I39
"	II.00 "	88	I38	I39
"	I2.00	88	I36	I38
"	I.00PM	86	I36	I39
"	2.00 "	87	I37	I40
"	3.00 "	86	I37	I40
"	4.00 "	89	I36	I39

Table 6 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/24/20	5.00PM	90	I37	I40
3/25/20	8.00AM	87	I50	I54
"	I2.00	86	I50	I54
"	I.00PM	85	I48	I50
"	2.00 "	82	I47	I48
"	3.00 "	83	I47	I50
"	4.00 "	84	I46	I50
"	5.00 "	84	I48	I5I
"	5.30 "	86	I48	I52

Table 6 (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	I50	2.30	83	83	I8I	I03.5	97
2	300	4.60	90	90	278	I23	I87
3	450	7.40	90	90	378	I38.5	288
4	600	I0.I0	86	86	46I	I50	375

Table 6 (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
1	150	0.550	2.15	1.600	74.3	510
2	300	0.552	2.62	2.068	78.9	1020
3	450	0.556	3.15	2.594	82.3	1530
4	600	0.570	3.80	3.230	84.8	2040

Table 7

85% Magnesia Covering

Size of pipe, inches..................5

Thickness of covering, nominal, in....I

Thickness of covering, actual, in..I.IO

Weight per foot of length, lbs.....2.47

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/8/20	I.00PM	I50	2.88	80
"	2.00 "	"	2.85	8I
"	3.00 "	"	2.90	8I
"	4.00 "	"	2.90	84
"	5.00 "	"	2.75	83
"	6.00 "	"	2.85	83
3/9/20	I.00 "	300	5.43	86
"	2.00 "	"	5.43	87
"	3.00 "	"	5.44	87
"	4.00 "	"	5.45	87
"	5.00 "	"	5.46	89
3/I0/20	I.00 "	450	8.50	86

Table 7 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/I0/20	2.00PM	450	8.50	86
"	3.00 "	"	8.50	87
"	4.00 "	"	8.49	88
"	5.00 "	"	8.50	88
3/II/20	I2.00	600	II.25	89
"	I.00PM	"	II.50	90
"	2.00 "	"	II.75	90
"	3.00 "	"	II.75	9I
"	4.00 "	"	II.75	9I
"	5.00 "	"	II.90	9I
"	6.00 "	"	II.70	9I

Table 7 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/8/20	1.00PM	80	103	100
"	2.00 "	81	103	100
"	3.00 "	81	103	100
"	4.00 "	84	103	101
"	5.00 "	83	103	101
"	6.00 "	83	103	101
3/9/20	1.00 "	86	120	117
"	2.00 "	88	124	119
"	3.00 "	87	123	119
"	4.00 "	87	123	123
"	5.00 "	89	126	122
3/10/20	1.00 "	87	136	130
"	2.00 "	88	136	130
"	3.00 "	88	137	133
"	4.00 "	88	136	132
"	5.00 "	89	138	133
3/11/20	12.00	90	152	146

Table 7 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/II/20	I.00PM	9I	I53	I48
"	2.00 "	9I	I53	I49
"	3.00 "	92	I55	I5I
"	4.00 "	92	I56	I52
"	5.00 "	93	I57	I53
"	6.00 "	93	I56	I53

Table 7 (continued)

Average Results.

No. Of Run.	Watts	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	I50	2.85	83	83	203	I02.5	I20
2	300	5.46	89	89	309	I24	220
3	450	8.50	88	88	4I3	I35.5	325
4	600	II.70	9I	93	5I5	I54.5	424

Table 7 (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost Per Hr.
1	150	0.452	2.240	1.788	79.9	518
2	300	0.470	2.780	2.310	82.8	1000
3	450	0.492	3.430	2.938	85.5	1530
4	600	0.510	4.250	3.740	88.0	2060

Table 8

Asbesto-Cel. Covering.

Size of pipe, inches..................5

Thickness of covering, nominal, in...I

Thickness of covering, actual, in.I.I0

Weight per foot of length, lbs....2.48

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/I5/20	I.00PM	I50	2.70	77
"	2.00 "	"	2.70	78
"	3.00 "	"	2.43	79
"	4.00 "	"	2.43	8I
3/I6/20	2.00 "	"	2.8I	86
"	3.00 "	"	2.67	90
"	4.00 "	"	2.57	88
"	5.00 "	"	2.50	87
"	6.00 "	"	2.47	86
"	7.00 "	"	2.40	86
"	8.00 "	"	2.40	84
"	9.00 "	"	2.40	84
3/I7/20	I.00 "	300	4.75	82

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Table 8 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/17/20	2.00PM	300	4.82	83
"	3.00 "	"	4.83	84
"	4.00 "	"	4.84	84
"	5.00 "	"	4.80	84
3/18/20	1.00 "	450	7.00	82
"	2.00 "	"	7.00	83
"	3.00 "	"	7.00	82
"	4.00 "	"	7.10	84
"	5.00 "	"	7.10	86
3/19/20	1.00 "	600	11.56	85
"	2.00 "	"	9.00	82
"	3.00 "	"	9.15	84
"	4.00 "	"	9.40	85
"	5.00 "	"	9.50	83
"	7.30 "	"	9.80	87
"	9.15 "	"	9.80	86

Table 8 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/15/20	1.00PM	77	99	97
"	2.00 "	78	99	98
"	3.00 "	79	99	98
"	4.00 "	80	99	98
3/16/20	2.00 "	86	108	106
"	3.00 "	90	109	107
"	4.00 "	89	108	103
"	5.00 "	88	108	106
"	6.00 "	86	106	104
"	7.00 "	86	107	105
"	8.00 "	84	104	103
"	9.00 "	84	104	103
3/17/20	1.00 "	82	113	115
"	2.00 "	82	116	117
"	3.00 "	84	117	119
"	4.00 "	85	119	118
"	5.00 "	85	118	117

Table 8 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/I8/20	I.00PM	82	I35	I35
"	2.00 "	82	I33	I33
"	3.00 "	82	I32	I32
"	4.00 "	84	I34	I34
"	5.00 "	86	I34	I34
3/I9/20	I.00 "	85	I4I	I43
"	2.00 "	82	I42	I44
"	3.00 "	83	I45	I45
"	4.00 "	85	I48	I50
"	5.00 "	83	I47	I48
"	7.30 "	87	I52	I52
"	9.I5 "	86	I5I	I5I

Table 8 (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	I50	2.40	84	84	I85	I03.5	IOI
2	300	4.80	84	85	279	II7.5	I95
3	450	7.I0	86	86	36I	I34	277
4	600	9.80	86	86	452	I5I	366

Table 8 (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
I	I50	0.528	2.I6	I.632	75.5	5IO
2	300	0.544	2.64	2.096	79.3	IOIO
3	450	0.570	3.I2	2.550	8I.8	I525
4	600	0.585	3.72	3.I35	84.3	2040

Table 9

Sponge Felt Covering No. 7

Size of pipe, inches........................5

Thickness of covering, nominal, in.....1.5

Thickness of covering, actual, in.....1.54

Weight per foot of length, lbs........6.76

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/30/20	2.00PM	100	3.39	88
"	3.00 "	"	2.95	88
"	4.00 "	"	2.80	88
"	5.00 "	"	2.60	89
"	6.00 "	"	2.40	90
"	7.00 "	"	2.31	90
"	8.00 "	"	2.22	90
"	9.00 "	"	2.20	88
"	10.00 "	"	2.20	88
3/31/20	1.00 "	600	12.80	88
"	2.00 "	"	13.00	88
"	3.00 "	"	13.10	87
"	4.00 "	"	13.10	87

Table 9 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
3/31/20	5.00PM	600	13.20	87
"	6.00 "	"	13.20	87
4/1/20	1.00 "	270	5.70	84
"	2.00 "	"	5.68	82
"	3.00 "	"	5.68	84
"	4.00 "	"	5.62	86
"	5.00 "	"	5.62	84
4/2/20	1.00 "	430	8.82	81
"	2.00 "	"	8.80	82
"	3.00 "	"	8.80	82
"	4.00 "	"	8.80	82
"	5.00 "	"	8.80	82

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Table 9 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
3/30/20	2.00PM	88	I09	I09
"	3.00 "	88	I09	I08
"	4.00 "	89	I07	I07
"	5.00 "	90	I06	I06
"	6.00 "	9I	I06	I07
"	7.00 "	90	I05	I05
"	8.00 "	90	I05	I05
"	9.00 "	88	I03	I03
"	I0.00 "	88	I03	I03
3/3I/20	I.00 "	88	I55	I59
"	2.00 "	88	I54	I58
"	3.00 "	87	I54	I58
"	4.00 "	87	I54	I60
"	5.00 "	88	I55	I6I
"	6.00 "	88	I56	I6I
4/I/20	I.00 "	84	II4	II6
"	2.00 "	82	II4	II4

Table 9 (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
4/I/20	3.00PM	84	II6	II7
"	4.00 "	86	II8	II6
"	5.00 "	84	II5	II6
4/2/20	I.00 "	8I	I23	I25
"	2.00 "	8I	I26	I28
"	3.00 "	82	I26	I28
"	4.00 "	82	I26	I28
"	5.00 "	82	I26	I28

Table 9 (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	I00	2.20	88	88	I80.5	I03	92.5
2	270	5.62	84	84	3I0	II5.5	226
3	430	8.80	82	82	4I7	I27	335
4	600	I3.20	87	87.5	556	I58.5	469

Table 9 (continued)

Average Results.

NO. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
I	I00	0.384	2.I4	I.756	82.I	340
2	270	0.425	2.80	2.375	84.8	920
3	430	0.456	3.47	3.0I4	86.8	I470
4	600	0.455	4.20	3.745	89.2	2040

Table IO

Covering No. 8

Size of pipe, inches.................5

Thickness of covering, nominal, in...I

Thickness of covering, actual, in.I.I2

Weight per foot of length, lbs....5.54

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
4/I6/20	I.00PM	90	2.00	82
"	2.00 "	"	I.95	83
"	3.00 "	"	I.9I	84
"	4.00 "	"	I.87	84
"	5.00 "	"	I.85	84
4/I9/20	I.00 "	200	4.28	84
"	2.00 "	"	4.2I	80
"	3:00 "	"	4.07	82
"	4.00 "	"	3.90	84
"	5.00 "	"	3.80	84
4/20/20	3.00 "	"	3.30	85
"	4.00 "	"	3.35	85

Table I0 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
4/20/20	5.00PM	200	3.40	82
"	6.00 "	"	3.47	82
4/2I/20	II.00AM	"	3.50	87
"	I2.00	"	3.47	87
"	I.00PM	"	3.45	88
"	2.00 "	"	3.42	86
"	3.00 "	"	3.42	84
"	4.00 "	"	3.47	84
"	5.00 "	"	3.48	84
4/23/20	2.00 "	350	5.80	85
"	3.00 "	"	5.8I	84
"	4.00 "	"	5.86	86
"	5.00 "	"	5.90	87
"	7.30 "	"	5.93	89
4/26/20	3.00 "	I00	I.93	84
"	4.00 "	"	I.84	84
"	7.30 "	"	I.74	86
"	9.30 "	"	I.72	86

Table I0 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
4/29/20	I.00PM	I00	I.76	86
"	2.00 "	"	I.76	85
"	3.00 "	"	I.76	84
"	4.00 "	"	I.76	86
"	5.00 "	"	I.76	86
4/30/20	2.00 "	320	5.62	86
"	3.00 "	"	5.42	8I
"	4.00 "	"	5.48	87
"	5.00 "	"	5.48	88
"	7.30 "	"	5.50	90
5/3/20	2.00 "	450	7.80	79
"	3.00 "	"	7.80	79
"	4.00 "	"	7.85	82
"	5.00 "	"	7.84	8I
5/6/20	8.30AM	560	I0.30	82
"	I2.00	"	I0.30	82

Table 10 (continued)

Date	Time	Watts	Milli-volts	Temp. Cold end Deg. Fahr.
5/7/20	2.00PM	65	0.663	86
"	3.00 "	"	0.68	86
"	4.00 "	"	0.68	88
"	5.00 "	"	0.75	86

Table IO (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
4/I6/20	I.00PM	82	95	96
"	2.00 "	82	99	98
"	3.00 "	83	I00	I02
"	4.00 "	84	99	I0I
"	5.00 "	84	99	I0I
4/I9/20	I.00 "	83	II4	I24
"	2.00 "	80	II0	II6
"	3.00 "	82	III	II7
"	4.00 "	84	II3	II8
"	5.00 "	84	II2	II8
4/20/20	3.00 "	85	II0	II4
"	4.00 "	84	II0	II4
"	5.00 "	8I	I08	II2
"	6.00 "	8I	I07	II2
4/2I/20	II.00AM	87	II0	II5
"	I2.00	87	III	II6
"	I.00PM	88	II2	II6
"	2.00 "	86	III	II5

Table IO (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
4/2I/20	3.00PM	84	I08	II4
"	4.00 "	83	I09	II4
"	5.00 "	83	I09	II4
4/23/20	2.00 "	84	I26	I30
"	3.00 "	84	I24	I32
"	4.00 "	86	I27	I32
"	5.00 "	87	I28	I34
"	7.30 "	88	I3I	I3I
4/26/20	3.00 "	84	98	I00
"	4.00 "	84	99	I0I
"	7.30 "	86	99	I02
"	9.30 "	86	98	I00
4/29/20	I.00 "	86	99	I02
"	2.00 "	85	98	I00
"	3.00 "	83	97	I00
"	4.00 "	86	I00	I03
"	5.00 "	86	99	I02
4/30/20	2.00 "	86	I25	I30

Table IO (continued)

Date	Time	Temp. Room Deg. Fahr.	Temp. Under Canvass Deg. Fahr.	
4/30/20	3.00PM	8I	I25	I3I
"	4.00 "	87	I26	I3I
"	5.00 "	88	I27	I32
"	7.30 "	90	I28	I33
5/3/20	2.00 "	78	I3I	I4I
"	3.00 "	78	I32	I42
"	4.00 "	8I	I35	I43
"	5.00 "	80	I34	I42
5/6/20	8.30AM	82	I5I	I60
"	I2.00	82	I5I	I6I
5/7/20	2.00PM	86	94	94
"	3.00 "	86	94	94
"	4.00 "	88	95	96
"	5.00 "	86	93	95

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table IO (continued)

Average Results.

No. Of Run.	Watts.	Millivolts.	Temp. Cold End Deg. Fahr.	Temp. Room Deg. Fahr.	Temp. Of Pipe Deg. Fahr.	Temp. Under Canvass, Mean.	Temperature Difference Deg. Fahr.
I	I00	I.76	86	86	I60.5	I00.5	74.5
2	200	3.48	84	83	227	III.5	I43
3	320	5.50	89.5	89.5	3I0.5	I30.5	22I
4	350	5.93	89	88	327	I34	238
5	450	7.84	8I	80	384	I38	303

Table 10 (continued)

Average Results.

No. Of Run.	Watts.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	B.T.U. Lost/ Sq. Ft./ Deg. Temp. Difference/ Hr. Bare Pipe.	B.T.U. Saved/ Sq. Ft./ Deg. Temp. Difference/ Hr. Due To Covered Pipe.	Efficiency Per Cent.	Total B.T.U. Lost/ Hr.
1	100	0.478	2.05	1.572	74.5	340
2	200	0.497	2.35	1.853	78.8	680
3	320	0.515	2.74	2.275	81.6	1090
4	350	0.522	2.90	2.378	82.0	1190
5	450	0.528	3.28	2.752	83.9	1530

Table II

Heat loss in B.T.U. per sq. ft. per deg. temp. difference per inch of thickness per hour for a temp. difference of 300 deg. fahr. - as determined from the formula

$$k = \frac{W_1 r_1 (\log_e r_1 - \log_e r_2)}{\theta_1 - \theta_2}$$

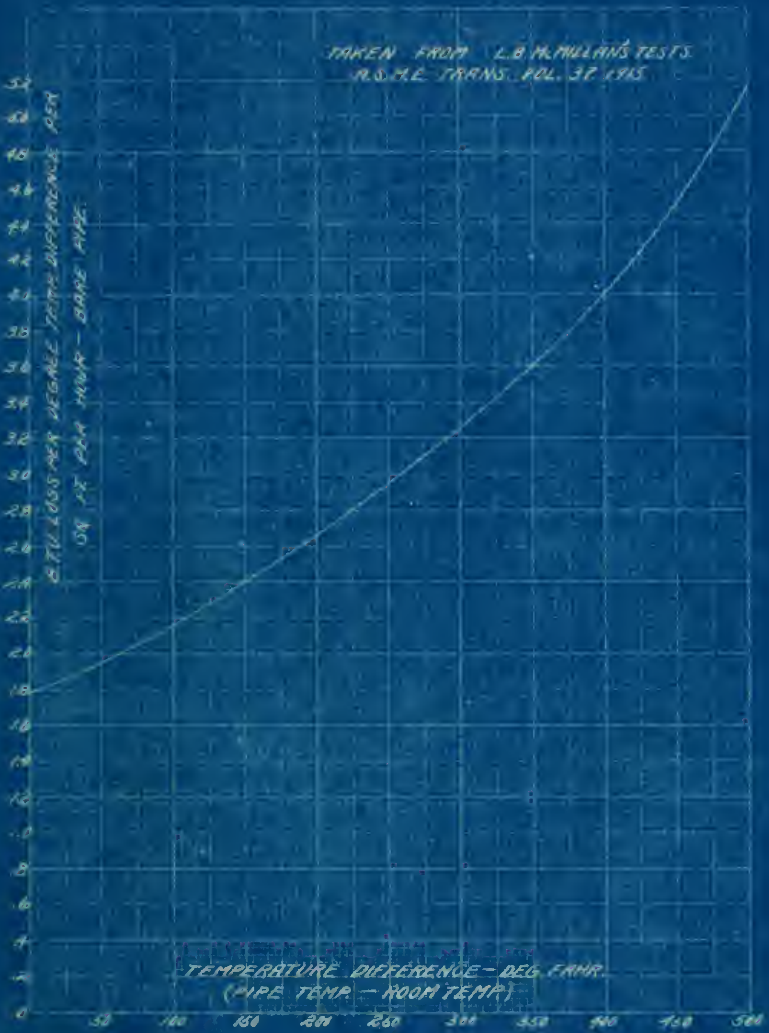
Covering.	B.T.U. Loss/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	Value of W_1	Value of r_1	Value of r_2	Value of θ_1	Value of θ_2	Value of k.
Sponge Felt No.1	0.363	108.9	4.78	2.78	300	33	0.617
Sponge Felt No.2	0.654	196.2	3.59	2.78	300	67	0.608
Sponge Felt No.3	0.279	83.7	5.91	2.78	300	22.8	0.639

Table II (continued)

Covering.	B.T.U. Loss/ Sq. Ft./ Deg. Temp. Difference/ Hr. Covered Pipe.	Value of W_1	Value of r_1	Value of r_2	Value of θ_1	Value of θ_2	Value of k.
Sponge Felt No.4	0.549	164.7	3.83	2.78	300	55.2	0.598
Sponge Felt No.5	0.452	135.6	3.68	2.78	300	48.9	0.420
85% Magnesia 10 yrs. old	0.560	168	3.76	2.78	300	57.0	0.592
85% Magnesia	0.570	171	3.88	2.78	300	56.5	0.645
Sponge Felt No.7	0.439	131.7	3.88	2.78	300	45.8	0.474
Sponge Felt No.8	0.533	159.9	4.32	2.78	300	49.7	0.793
Asbesto-Cel.	0.487	146.1	3.90	2.78	300	49.5	0.552

Chapter 5.

CONCLUSION.



TAKEN FROM L.B. McMILLAN'S TESTS.
A.S.M.E. TRANS. VOL. 37 1915.

The results of test on bare pipe, taken from L. B. McMillan's treatise, A. S. M. E. Trans., Vol. 37, 1916, are shown in Fig. 4. The ordinate of any point is the net heat loss per degree temperature difference per sq. ft. per hour, and the abscissa represents difference between pipe temperature and room temperature. This curve indicates that the heat losses are made up of two components, each of which tends to cause the losses to increase with temperature at a much more rapid rate than that at which the temperature itself increases. These are radiation and convection. According to Stefan's law, the radiation varies as the fourth power of the absolute temperature. The velocity of convection currents also increases much more rapidly than the temperature; therefore, a combination of these two effects will cause the resultant losses to increase with

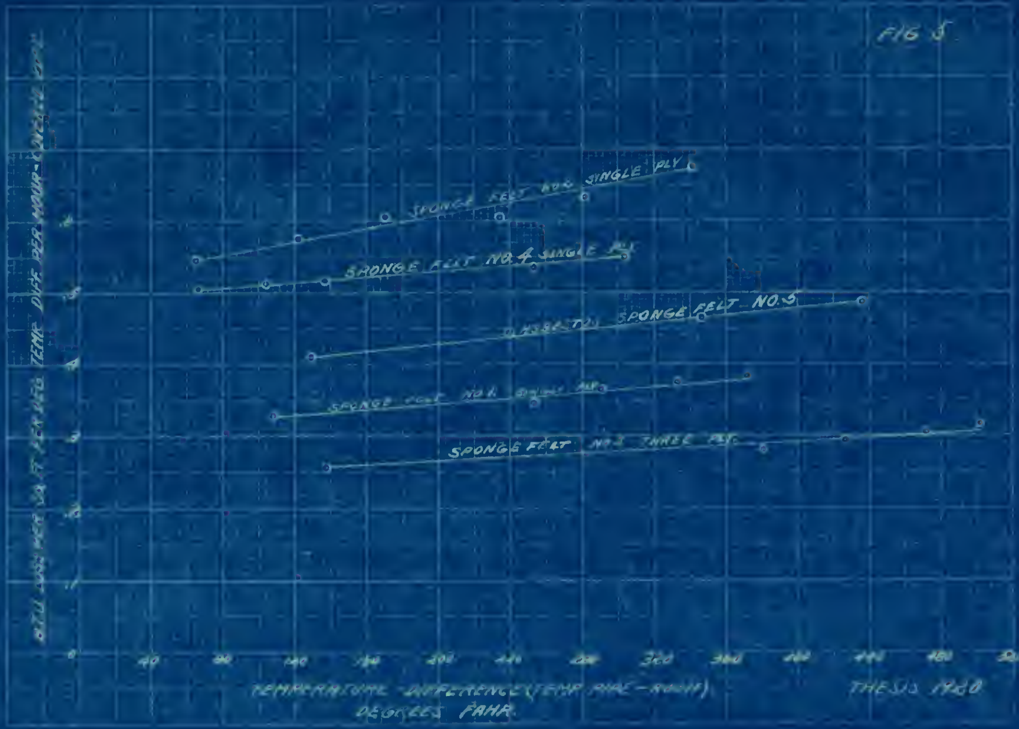


FIG 5

THESIS 1920

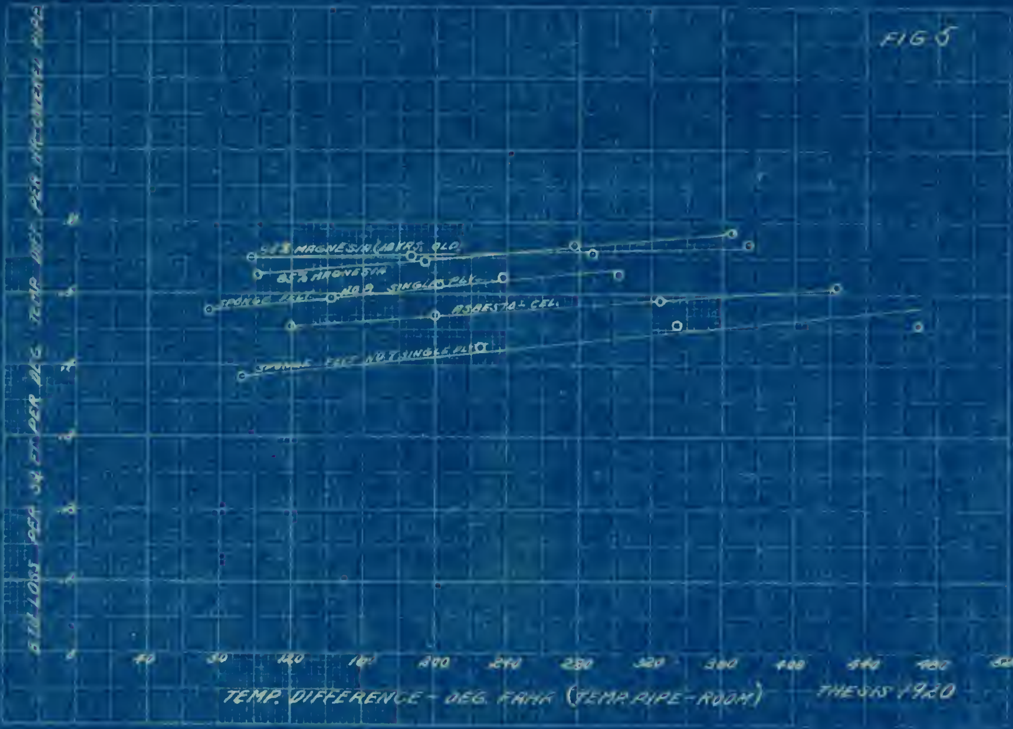


FIG 5
85% MAGNESIA (10 YRS. OLD)
85% MAGNESIA
NO. 2 SINGLE PLY
SPONGE FELT
ASBESTOS CEL.
SPONGE FELT NO. 1 SINGLE PLY
B.T.U. LOSS PER SQ. FT. PER DEG. TEMP DIFF. PER HR. COVERED PIPE
0
40
80
120
160
200
240
280
320
360
400
440
480
520
TEMP. DIFFERENCE - DEG. FAHR. (TEMP. PIPE - ROOM)
THESIS 1920

temperature much more rapidly than does temperature itself.

Fig. 5 shows curves from tests of the ten different coverings. The ordinate and abscissa represent the same items as for the bare pipe curve. These curves slope upward as the temperature difference increases, which indicates they are similar to the rate curve for bare pipe, though they do not bend nearly so rapidly; that is, the effect of radiation and convection within the covering itself and at the surface increases much more rapidly than the temperature itself, but not nearly as much as in the case of the bare pipe.

It is noticeable, further, that some curves are nearly parallel to the temperature axis and that others slope much more rapidly. The reason for this is that the

rate of heat flow depends upon the material of the covering and upon its structure. For instance, in a covering with air pockets, the heat loss will increase much more rapidly with the increase of temperature difference than in case of a solid one, because in the former heat is transmitted through those air spaces in addition to the conduction of the solid material.

Appendix I.

MATHEMATICAL TREATMENT OF HEAT FLOW IN INSULATING MATERIALS.

Mathematical Treatment of Heat Flow in Insulating Materials.

Taken from artical by L. B. McMillan. A.S.M.E. Transactions. Vol.37 Page 960.

In the case of flat surfaces, where the two boundaries of the insulating material are parallel, the quantity of heat conducted is given by the equation

$$Q = k \frac{\theta_1 - \theta_2}{x} At$$

in which

Q is the quantity of heat conducted,

θ_1 and θ_2 the temperature of hotter and colder surfaces respectively,

x is the thicknessin in. of the layer of material,

A is the area in sq. ft. of the surface considered,

t is the time in hr.

k is the conductivity of the material in B. T. U. per degree temp. difference per sq. ft. per in. thickness per hr.

For testing pipe coverings which involve cylindrical surfaces rather than flat ones, the rate of heat flow is given by the equation

$$W_1 = \frac{k(\theta_1 - \theta_2)}{r(\log_e r_2 - \log_e r_1)}$$

in which

W is the rate of heat flow per sq. ft. per hr.;

k is the conductivity;

θ_1 and θ_2 are the temperatures;

r_1 and r_2 are the radii of the inner and outer surfaces of the covering respectively;

r is the outside radius of the pipe.

Solving for k

$$k = \frac{W_1 r(\log_e r_2 - \log_e r_1)}{\theta_1 - \theta_2}$$

In this equation everything is known except θ_1. Now the loss per sq. ft. of outside surface of the covering, W_2, is a function of the temperature difference between the

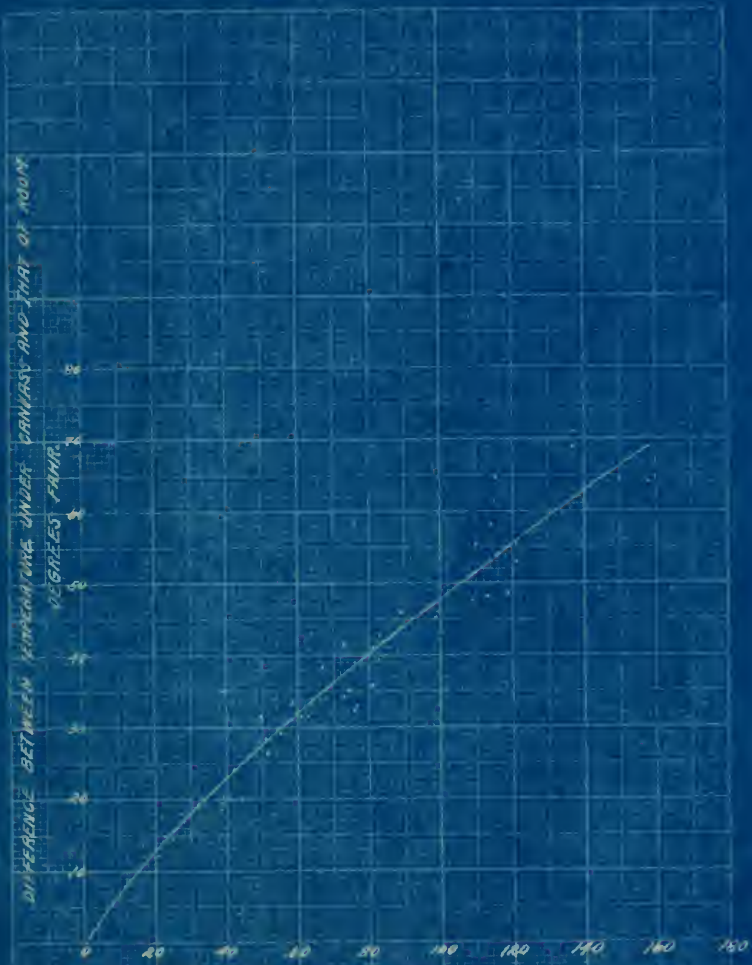


FIG 6
THESIS 1920

outside surface of the covering and the air in the room.

$$W_2 = \frac{r_1}{r_2} W_1$$

The relation between W_2 and the temperature difference between the outside surface of the covering and the room, for the coverings tested was established, the results of which are shown in the form of a curve in Fig. 6.